Physics of Seismic Interface Waves in the Surf Zone

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Award # N00014WR30089

LONG TERM GOAL

Our long term goal is to develop the basic physics of micro seismo-acoustics so as to enable the development of seismic sonar for the detection of ordnance buried in sea floor sediments.

OBJECTIVES

We seek to determine the potential of the seismo-acoustic interface waves for the detection of objects buried just beneath the water-sediment or air-sediment interface. We need to determine the unique potential of the various types of seismo-acoustic interface waves (ie Rayleigh, Scholte, Love, Lamb, etc.) for this purpose. We want to determine how these different wave types propagate in the surf zone sediments, and which may be best suited for the purpose at hand. Finally, we seek to determine the potential for discrete excitation of individual seismo-acoustic wave types.

APPROACH

Our primary purpose has been to explore the experimental science of seismic interface waves in *real* media, for which there is no theory. Exploration seismology is highly developed in the petroleum industry, but there the interface waves are considered to be “noise” and little has been done to understand them, only to suppress them. Although considerable knowledge has been developed for interface waves in earthquake seismology, little is known about the physics appropriate for tactical military applications of seismic interface waves, which is really a topic in “micro seismology”.

Our research tools have included a mobile instrument vehicle, seismic sources and seismometers we have developed from commercial components, computerized data acquisition and analysis systems, and our experimental venue is the Navy beach on Monterey Bay, adjacent to the Naval Postgraduate School (NPS).

Our methods are built on several prior years of both theoretical and experimental research sponsored by ONR Code 321OA, Dr Jeffrey Simmen, PM, at the University of Texas at Austin. There, Dr. Eric Smith, a Postdoctoral Fellow developed a theory for the seismic interface wave refection from buried objects [see PUBLICATIONS, below].

For the work described here, our staff included Thomas Muir, NPS Chair Professor of Mine Warfare, who teaches this subject, provides overall guidance in the art, and was responsible for the “wet end” of the experimental research. Associate Professor of Physics, Steven Baker, teaches acoustical physics and

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
1998		**00-00-1998 to 00-00-1998**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Physics of Seismic Interface Waves in the Surf Zone	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Postgraduate School,Department of Physics,Monterey,CA,93943**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002252.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**5**	

acoustical engineering and was responsible for the “dry end” of the experimental research, including transducer design and digital data recording.

During the course of this work, we were fortunate fo have a superlative graduate student, LT Frederick E. Gagan Jr., USN. During his two years at NPS, LT Gagan earned a Master of Science Degree in Physics, *With Distinction*, a Master of Science Degree in Acoustical Engineering, *With Distinction;* and he also won the Chief of Naval Operations Award for Excellence in Undersea Warfare and Military Bearing, all presented to him at formal NPS graduation ceremonies in March 1998. He also passed the initial screening exams for the PhD degree in Physics, and completed all but one course required for that degree. He also completed approximately half of the requirements for a Masters Degree in Naval Tactics and Doctrine, offered by extention from the Naval War College, and taught by NPS professors, at night. LT Gagan is an Explosives Ordnance Disposal (EOD) officer, and has returned to the fleet as executive officer of a multi service EOD training unit at Egland Air Force Base in Florida. As soon as he gets “settled in”, we at NPS, along with doctoral staff of the Naval Coastal Systems Station (CSS) in Panama City FL, will set in motion a means for LT Gagan to complete his PhD in Physics from NPS, and it would be appropriate if he could have the opportunity to do a dissertation topic on the detection of buried mines. Professors are, of course, proud of their work, but they can be even more proud of their students. It was indeed an honor and a pleasure for both of us to teach Fred Gagan, to design experiments with him, and to go to sea with him, making measurements with him in the surf zone of Monterey Bay.

WORK COMPLETED

The results of our work on this specific task for are described in adequate detail in LT Fred Gaghan’s thesis, listed below under “PUBLICATIONS”. In order to overcome the confusing effects of the excitation of many different types of compressional and shear waves in sea floor sediments, each of which travels with its own unique velocity, we attempted to discretely excite Rayleigh waves, which travel in elliptical orbits in the vertical and radial planes. Several exploratory sources were developed to produce this type of excitation at the sediment surface. A number of field tests were conducted with experimental sources, developed with commercial products such as “bass shakers”. Several configurations were tested, including shakers that were orthogonally coupled to a plate in contact with the sediment.

RESULTS

Perfect, discrete Rayleigh wave excitation was not achieved in the vicinity of the experimental sources. However, it was found that the medium itself acted as a selective filter for Rayleigh interface waves after a few tens of meters of propagation. It was determined that a seismic sonar for buried ordnance detection at a few meters range might be subject to the confusing effects of the interference of multiple wave types and reverberation, while a seismic sonar operating at a few tens of meters range might be immune from these difficulties. This pointed us in the direction of sources with higher source levels, which are required for longer range propagation.

IMPACT/IMPLICATIONS

Our research is at the center of both basic science, tactical naval and military applications and humanitarian need. It is extremely difficult to detect buried ordnance. The world's only operational systems are the marine mammal detachments of the US Navy EOD forces. The dolphins and their sonar systems are very good, but they do not like the very shallow water of the pounding surf zone and they do not operate on the beach, the sand dunes and beyond. Underwater sonar employing synthetic aperture technology has been researched and developed by CSS, and shows great promise, but applications of this technology in the pounding surf and on the beach are more difficult.

In terms of basic science, we have had some much appreciated opportunities to work on this challenging and difficult problem. We are working out the theory and the experimental science of a small niche in seismo-acoustics that is uncharted. It has obvious scientific products that have already gone into the annals of classical physics and oceanography, and can with good probability continue to so proceed [see PUBLICATIONS, below].

In terms of tactical naval and military applications, we need but point to the projection of naval power ashore, which has historically been hampered by the deployment of mines. We need not belabor this point, because it is well known. History has shown that third world countries, without navies, have taken control of seas and amphibious assault areas thought to be controlled by the US, by utilizing "weapons of 19 th century technology, deployed by vessel types, known during the time of the Roman Empire".

In terms of humanitarian needs, there may be over 100 million mines and bombs left behind in 62 third word countries, most all of them buried. Remediation is not just for highly paid defense contractors. Every day, US soldiers, sailors, airmen and marines go in harm's way to deal with buried ordnance at their foreign duty stations. The real victims are mostly civilians, who can't return to their homes in former war zones, and the casualty rate (maimed or killed) for those that do return, can run as high as 25,000 a year, mostly women and children, almost 3 per hour. No satifactory technological solution exists for the remote detection of buried ordnance at the present time, although a number of electromagnetic technologies are being researched and developed.

Should we be allowed to complete this research, we could put the appropriate science and technology in the hands of those who could provide robotic systems to be deployed ashore, to counter buried ordnance, for both tactical and humanitarian purposes.

TRANSITIONS

The present research was funded on a two year basis, starting in FY97. In FY98, the applications side of the house in ONR Code 321, under Dr Douglass Toderoff, PM, mine warfare, undertook to support some at-sea measurements of seismo-acoustic target strengths, for the continued development of the seismic sonar concept for the detection of buried ordnance. This new work augmented that already supported by Dr Jeffrey Simmen, ocean acoustics. This transition enabled the support of two more naval officer research efforts under professors Muir and Baker; one by LT Sean Michael Fitzpatrick, USN, and another by MAJ Patrick M. Hall, USMC, who will both graduate in December 1998, and return to the fleet.

The thesis research of LT Fitzpatrick involves the further development of much improved seismic sources, as well as extensive research on the propagation and signal processing of seismic interface waves. LT Fitzpatrick is a naval flight officer (E2 Hawkeye community) and his energy, intelligence, and devotion is remarkable. He will be receiving dual Master of Science Degrees in Mechanical Engineering and in Physics. He has also been nominated for the Naval Sea Systems Command Award for Excellence in Combat Systems and Military Bearing. He was an outsanding student in the NPS class on undersea weapons [Muir's course on mine and torpedo warfare], where he did a thoughtful essay on what high altitude, carrier based, surveillance aircraft could do in support of mine warfare, if need be. LT Fitzpatrick's essay is publishable in a professional naval officer journal. LT Fitzpatrick's Masters Degree thesis contains results eminently publishable in the American Physical Society's *Journal of the Acoustical of America* (JASA) as well as the Institute of Electrical and Electronic Engineer's *Journal of Oceanic Engineering* (JOE).

It has indeed been a rewarding experience to be among LT Fitzpatirick's supervising professors. Please excuse; but <u>enjoy</u> the following, "sea story". *The lieutenant is standing in the shallow surf zone next to his professor, both in their waders, with instruments and targets deployed, the experimental sonar a few meters away, atop a dune buggy. It is getting dark. The lieutenant is using a laptop computer to process seismic sonar echoes from a buried target. The tide is coming in. The lieutenant is doing Hilbert transforms on the seismic echoes, a signal processing technique. The waves lap over our knee high rubber boots, they fill with sea water. The professor decides its time to go ashore, and so suggests to the lieutenant. "Wait a minute Professor, after all this work, we've almost got it". The professor goes ashore for the wet suits, life lines and preservers. By the time he returns, the lieutenant has it all wrapped up; data set in hand, analyzed, experiment completed, back on the buggy, headed for the Navy schoolhouse.*

The thesis research of MAJ Hall involves the actual seismic target strength of minelike objects buried in wet sediments. MAJ Hall, a graduate of the U.S. Naval Academy, is an amphibious assault officer. One of his recent tours of duty was as company commander of an Amphibious Assault Vehicle (AAV) squadron, commanding some 52 AAV's, whose job it is, to safely land the infantry, in the final stages of projecting Naval Forces ashore. As such, he has a vested interest in the clearance of minefields that threaten amphibious assaults. One of us (Muir) nominated MAJ Hall for the United States Marine Corps Superior Service Award, which is based on thesis research, military bearing and community service. We have just been informed that MAJ Hall won this award, which will be presented to him by RADM Robert Chaplin, USN, at graduation ceremonies in December 1998. His thesis research is eminently publishable in professional naval service journals, such as the *US Naval Institute Proceedings*, as well an in the American Physical Society's *Journal of the Acoustical of America* (JASA) as well as the Institute of Electrical and Electronic Engineer's *Journal of Oceanic Engineering* (JOE).

It has also been a rewarding experience to be among MAJ Hall's supervising professors. He is not only a physicist who understands the theory of elasticity, he is also an experimentalist who gets things done in the surf zone. A conclusion of Postdoctoral Fellow Erick Smith's work was that the seismic target strength of a buried object was dominated by its mass. MAJ Hall's thesis research addressed this difficult issue. Please excuse; but <u>enjoy</u> the following, "sea story". *The Major, although an officer, often commanding hundreds of Marines, readily accepts the role of graduate student , which means that he does his own field work, just like other graduate students in universities all across the country.*

He undertakes to settle the experimental issues of target strength vs target mass. He surveys the physics department and comes up with an argon gas bottle and a quantity of lead bricks, which are promptly "requisitioned" from the linear accelerator lab. The gas bottle is cut open and we go to the beach, where he incrementally stuffs these lead blocks inside the steel (minelike) bottle, while measuring the seismic target strength as a function of enclosed mass. There are 26 lead weights, each weighing 26 pounds, and the professor tries to help the major carry them around. The major carries two at a time, one in each hand. The professor manages one at a time. Again the tide comes in and we are awash, and it gets dark. The professor thinks we have done enough, but the major says; "wait, professor, I've got a powder keg buried over there, and we have to get these weights in that target too, more measurements; its a different shape, you know". So out comes the 676 pounds of lead from the argon bottle, to be moved 20 yards to the powder keg, only to be removed once again, after the measurements, and rerturned to the accelerator lab, before the nuclear people realize something is missing.

This experiment worked; but with a new and unexpected twist. Although the seismic target strength increased with mass, it also was accompanied by a change in the echo waveform from one of a retrograde to prograde particle orbit. NPS intends to continue to pursue support on these important problems in both the 6.1 and 6.2 arenas, enabling us to develop solutions and to continue to introduce young naval officers to meaningful research projects.

REFERENCES

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"Measurement and localization of interface wave reflections from a buried target", by Eric Smith, Preston Wilson, Fred Bacon, Jason Manning, John Behrens, and Thomas Muir, J. Acoust Soc. Am., May 1998

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